NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2106

EVALUATION OF SEVERAL ADHESIVES AND PROCESSES FOR BONDING SANDWICH CONSTRUCTIONS OF ALUMINUM FACINGS ON PAPER HONEYCOMB CORE

By H. W. Eickner

Forest Products Laboratory

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SUMMARY

In preliminary tests, 6 of 14 bonding processes evaluated by tension tests on sandwich specimens of 1-inch aluminum cubes bonded to a resin-impregnated paper honeycomb core gave good-quality bonds which had average strengths of more than 350 psi or more than 75-percent failure in the core when tested at both 80° and 200° F.

The four bonding processes that had given the best results in the preliminary tests were used in a further investigation made to determine the effect of the amount of adhesive spread on the tensile strength of joints made between aluminum and resin-impregnated paper honeycomb core. All four bonding processes were found capable of producing good joints between the aluminum and paper honeycomb when moderately heavy spreads were applied to both core and facings. The use of lighter spreads or the application of the adhesive to only the core or facing usually resulted in lower-quality bonds, but with some of the adhesives the strength of the joints was sufficiently high for the lighter spreads to be considered satisfactory.

INTRODUCTION

Near the end of World War II, sandwich constructions consisting of high-strength facings bonded to opposite faces of a low-density core material were being extensively investigated for use in aircraft construction. The original emphasis in this development was on the use of balsa wood and foamed plastics as core materials. More recently, however, sheet metal, resin-impregnated paper, and resin-impregnated cotton and glass fabrics prepared in the form of honeycomb structures were developed as low-density core materials for use in aircraft sandwich constructions.

Certain problems occurred in bonding facings to these honeycomb core materials because of the small area of actual contact for bonding and because the large cells tended to entrap adhesive solvents and to produce blistering when the panels were hot-pressed. It was the purpose of this study to make a preliminary evaluation of a number of adhesive processes for bonding honeycomb-type cores to metal facings, and also to determine the amount of adhesive that should be spread when using the more promising adhesives and bonding procedures. For the purpose of this study, it was necessary to limit the investigation to one honeycomb core material, a resin-impregnated paper honeycomb having a density of about 6.5 pounds per cubic foot, in sandwich specimens with aluminum-alloy facings.

This investigation was conducted at the Forest Products Laboratory under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics.

I. PRELIMINARY EVALUATION OF ADHESIVE PROCESSES

Materials

Honeycomb core.- The honeycomb core material used was the Forest Products Laboratory standard "B" flute paper honeycomb prepared from 4.2-mil kraft paper and having a resin content of about 65 percent by weight of the completed core and a density of about 6.5 pounds per cubic foot.

The core material was first fabricated into blocks 4 feet long, 1 foot wide, and $2\frac{1}{2}$ inches thick. These blocks were then cut into sections $2\frac{1}{2}$ by $5\frac{1}{2}$ inches by $\frac{1}{2}$ inch thick. (See figs. 1 and 2.) The fabrication and cutting of this core material are described in references 1 and 2.

Facings.- One-inch cubes of 17S-T4 aluminum alloy (fig. 2) were bonded directly to the core material in this preliminary evaluation of adhesive processes. The faying surfaces of these cubes were first milled smooth. After these surfaces were milled, the cubes were washed in acetone, dried in air, and then immersed for 20 minutes at temperatures of 140° to 160° F in a solution of the following composition by weight: 10 parts of concentrated sulfuric acid, 1 part of sodium dichromate, and 30 parts of water. Upon removal from the solution, the cubes were rinsed in hot water and allowed to air-dry.

Adhesives.- The 14 adhesives or combinations of adhesives investigated in this part of the study for the bonding of impregnated paper honeycomb to aluminum facings are listed in table 1 together with the procedures used in applying them. Four of the bonding procedures used, B, D, E, and F, were two-stage processes in which a primer adhesive was applied and cured on the metal and a secondary adhesive was used to bond the primed metal to the core. The remaining processes were direct-bonding processes in each of which a single adhesive was employed, with the exception of process H which employed two adhesives in forming the direct bond between metal and core.

Fabrication of Test Specimens

Sixteen tension specimens of the sandwich type shown in figure 3 were prepared by each of the bonding processes evaluated. Specimens with each adhesive were prepared in a group by the use of the alining jig shown in figure 2. The bonding conditions used in preparing these specimens are listed in table 1, and were usually within the range recommended by the adhesive manufacturer.

The adhesives were applied on the clean or primed surface of the aluminum cubes with a brush or by spraying. On the small cubes it was difficult to obtain an accurate determination of the spreads applied; in general, however, the spreads were fairly heavy. Whenever a primer was used on the aluminum cube, it was sprayed on, allowed to air-dry, and then cured in an oven prior to the secondary bonding.

Adhesives were applied to the cores by brushing or by dipping the face of the core into a film of the adhesive that had been spread on a glass plate.

After the application of the adhesive and the open-assembly periods listed in table 1, the specimens were assembled. The procedure in assembling specimens was to place the 16 cubes with the spread surface turned up in the bottom of the alining jig (fig. 2), to lay the cores against the cubes, to insert the upper alining bars in the jig, and then to place the top 16 cubes in the jig with the spread faces against the core. A thin, end-grain balsa caul was used on both top and bottom of the assembly to equalize the pressure, and the entire assembly was pressed in an electrically heated hydraulic press. Following the pressing period given in table 1, the assembly was removed from the press and allowed to cool to room temperature. The jig was then disassembled, and the individual tension specimens were cut from the bonded section so that the edges of the core were even with the edges of the cubes.

Apparatus and Test Methods

After a conditioning period of at least 1 week at 80° F and 30-percent relative humidity, the bonded specimens were tested in tension.

The testing apparatus consisted of a set of testing grips, with a universal joint to eliminate effects of misalinement, in which the specimens were held by insertion of two pins (fig. 3), of an insulated cabinet (fig. 4) with elevated temperature control and a fan for circulation of air, and of a universal testing machine. The testing grips were placed in the inside of the cabinet and attached to the heads of the testing machine through the top and bottom of the cabinet.

For each of the 14 bonding processes evaluated, 8 specimens were tested at room temperatures (approximately 80° F), and 8 specimens were tested in the cabinet at 200° F. For the tests at 200° F, specimens were held in the insulated heated cabinet for 1 hour so that they might come to temperature equilibrium with the air in the cabinet, which was maintained at 200° F.

Each specimen was loaded to failure in tension by a head movement of 0.05 inch per minute. Maximum load at the instant of failure was recorded, together with the nature of the failure.

Test Results

The average results of tension tests at both 80° and 200° F on the sandwich specimens of aluminum bonded to impregnated paper honeycomb by means of different bonding processes are given in table 2.

Of the 14 bonding processes evaluated, 6 (B, C, E, F, G, and H) produced joints that were considered inferior in view of the results of the tests at 80° F. Judging from the appearance of the joints after testing, the bonding processes C and G failed to produce good joints because of insufficient flow of the adhesive; processes B, E, and F failed in adhesion to the primer; and process H failed in adhesion to the metal.

The other eight bonding processes (A, D, I, J, K, L, M, and N) produced good bonds, as shown by the tests at 80° F. The average failures with these processes were from 71 to 100 percent in the core material and the average tensile strengths were from 399 to 503 psi.

The tests at 200° F indicated a general lowering of the strength of the sandwich assemblies. The highest failing loads were obtained with processes A, D, and K, where the average tensile strengths were about 360 psi, with failures in the core of 100, 54, and 99 percent, respectively. Specimens bonded with processes L, M, and N showed average failures in the core of 77 to 88 percent, but the tensile strengths averaged only 231 to 292 psi. The lower strengths obtained with these last three bonding processes could be due to variations in the strength of the core or to the effect of the adhesive or of the curing cycle on the strength of the core.

The six processes that gave poor bonding at 80° F (B, C, E, F, G, and H) also gave low-strength bonds at 200° F, usually with no core failure. Bonding processes I and J gave somewhat higher values of strength and core failure at 200° F than did these six processes, but their tensile strengths were significantly lower in value than the corresponding values for processes A, D, K, L, M, and N.

II. DETERMINATION OF EFFECT OF SPREAD

The preceding preliminary study indicated that there are several processes that produce satisfactory bonding of paper honeycomb to aluminum when the adhesive spread is sufficiently heavy. Heavy spreads with the added weight and cost involved would not be warranted, however, if lighter spreads would produce equally good bonds. It was the purpose of the second part of the study, therefore, to determine the lower limits of adhesive spread that could be used to produce satisfactory bonding of paper honeycomb to aluminum facings with several of the better adhesive processes previously studied.

Materials

Honeycomb core.- Sections of impregnated paper honeycomb core of the same type and size as those used in part I were used.

Facings.- Because of the difficulty in accurately measuring the amount of adhesive spread on small surfaces, such as the faces of the 1-inch cubes used in part I of this study, $2\frac{1}{2}$- by 5-inch pieces of 0.020-inch alclad 24S-T3 aluminum-alloy sheet were used as facings on the paper honeycomb. The aluminum facings were cleaned first with acetone and then by immersion in a solution of sodium dichromate and sulfuric acid in the same manner as the aluminum cubes for part I.

Adhesives.- The four bonding processes selected for inclusion in this part of the study, based upon the results obtained in part I, were bonding processes A (using the two-part adhesive composed of phenol and polyvinyl resins), D (the two-stage process of metal-priming adhesive C used with an acid-catalyzed phenol resin as the secondary adhesive), and K and L (both using polyvinyl resins modified with phenol resins).

Fabrication of Test Specimens

Sandwich panels, $2\frac{1}{2}$ by 5 inches, were first prepared by bonding 0.020-inch alclad 24S-T3 aluminum-alloy facings to $\frac{1}{2}$-inch-thick paper honeycomb core by means of each bonding process and spread condition investigated.

The bonding conditions used in preparing these panels were, in general, the same as those listed for bonding processes A, D, K, and L in table 1. The exceptions were the amounts of adhesive spread, which were varied as shown in tables 3 to 6, and the precuring conditions, which were varied slightly in some instances with adhesives K and L, as shown in tables 5 and 6, respectively. Because the thin facings of the panels could be placed directly against the platens of the press where the joint would reach the desired temperature promptly, the total pressing periods were shorter than those used in part I, even though the joints were heated at the indicated curing temperatures for approximately the same lengths of time as those given in table 1.

After the panels had been removed from the press and cooled, the aluminum facings of the panels were cleaned by rubbing with steel wool. Clean aluminum cubes, as used in part I, were bonded to both facings of the sandwich with adhesive L in a manner similar to that used in part I when the cubes were bonded directly to the cores. Eight tension test specimens, similar in type to that shown in figure 3, were thus prepared from each $2\frac{1}{2}$- by 5-inch panel. One panel was prepared with each adhesive under each set of conditions.

Apparatus and Test Method

After a conditioning period of at least 1 week at 80° F and 30-percent relative humidity, the bonded specimens were tested in tension. The testing apparatus and method of testing were the same as those used for tests at room temperatures in part I of this study.

Test Results

The average results of the tension tests on specimens of resin-impregnated paper honeycomb bonded to aluminum facings by the four bonding processes when using various adhesive spreads are given in tables 3 to 6.

Bonding process A.- Each value cited in the text for bonding process A is the average of results of tests on the eight specimens cut from one panel. The complete results are given in table 3.

When no adhesive was applied to the core, adhesive spreads ranging from 10 to 25 grams per square foot on the facings gave joints of moderate strength (averages of 187 to 255 psi), with most of the failure in adhesion to the core. Increasing the spread rate slightly above 25 grams per square foot resulted in slightly stronger joints (305 psi) and more failure in the core, but with the narrow panels used in this study some blistering occurred. The blistering was caused by the adhesive solvents retained after air-drying. These solvents ruptured the bond between cell walls and forced the core material out of the edges of the sandwich panel. This type of blistering might not have occurred if the panels had been larger, or if the cells in the core had been bonded more firmly together.

When no adhesive was applied to the facings, adhesive spreads of 10 to 25 grams per square foot on the core resulted in bonds of moderately high strength (265 and 277 psi), but at the upper limit of this spread range some blistering occurred. Spreads greater than 25 grams per square foot resulted in lower joint strengths, edgewise blistering of the panels, and excessive foaming of the adhesive.

The results obtained on specimens when both core and facings were spread with adhesive were generally better than those obtained when adhesive was applied either to the core or to the facings alone. All the strengths were of a moderate to high quality (245 to 367 psi) regardless of the amount of spread within the range investigated - 6 to 30 grams dry spread per square foot on the facings and 6 to 35 grams per square foot on the cores. Blistering was not encountered as much in this series as in the previous series, where all the adhesive was applied to the core.

Bonding process D.- Each value cited in the text for bonding process D is the average of results of tests on the eight specimens cut from one panel. The complete results are given in table 4.

Wet spreads of 20 to 55 grams per square foot of the secondary adhesive on only the primed facings resulted in good specimens, which usually had strength values of more than 300 psi and 50-percent or more core failure. Best results (419 psi and 82-percent core failure) were obtained with the highest spread range investigated, 50 to 55 grams per square foot.

All the wet spreads of the secondary adhesive on the core only, within the range of 6 to 115 grams per square foot, resulted in only poor- or fair-quality bonds (114 to 227 psi) and high percentages of failure in adhesion to the primed metal facing.

Joints of moderately good quality (282 to 330 psi), with one exception, were obtained when wet spreads of 6 to 15 grams per square foot were applied on the facings and 10 to 30 grams per square foot on the core. The best-quality joints (320 psi and 93-percent core failure) were obtained with the heavier spread range of 10 to 15 grams per square foot on the facing and 25 to 30 grams per square foot on the core.

Bonding process K.- Each value cited in the text for bonding process K is the average of results of tests for eight specimens cut from one panel. The complete results are given in table 5.

Joints of very poor quality were obtained when all the panels were prepared with various amounts of adhesive spread only on the core or only on the facing material. The dry adhesive spreads investigated varied from 10 to 25 grams per square foot on the facings and from 7 to 30 grams per square foot on the core.

Of the dry spreads investigated where the adhesive was applied to both faying surfaces, only the heaviest spread, 15 to 20 grams per square foot on the facings and 20 to 25 grams per square foot on the core, gave good-quality joints having tensile strengths of 379 psi with 86-percent failure in the core.

All panels prepared with this bonding process were precured in the manner prescribed by the adhesive manufacturer. The precuring may have prevented blistering, but it may have also reduced the quality of the joints that were obtained when using single or light spreads, since precuring might be expected to reduce the flow characteristics of the adhesive.

Bonding process L.- Each value cited in the text for bonding process L is the average of results of tests on the eight specimens cut from one panel. The complete results are given in table 6.

When spreads were applied only to the core or only to the facings, joints of poor to fair quality generally resulted. When adhesive was applied only to the core, results were better than those obtained when a similar amount of adhesive was applied only to the facings. The best results with single spreading (approximately 250 psi and 50-percent core failure) were obtained when dry spreads of 15 to 25 grams per square foot were applied to the core.

Joints of fair to good quality (256 to 334 psi) resulted when dry spreads of 8 to 15 grams per square foot were applied to the facings and 8 to 60 grams per square foot were applied to the cores. However, in some instances, the use of the heavier spreads resulted in blistering of the same type as that obtained when using bonding process A. A few panels were prepared in which the adhesive was precured in an effort to avoid such difficulty. These panels did not blister, but low-strength joints were obtained. Heavier spreads than those used in these precuring experiments might result in good-quality joints when precured.

CONCLUDING REMARKS

From a study of a number of adhesive processes for bonding paper honeycomb cores to aluminum-alloy facings, it was found that in general the range of adhesive spread producing satisfactory joints was comparatively broad for each adhesive studied. Best results were ordinarily obtained when the adhesive was applied to both facings and cores.

The four bonding processes which were found to give the best-quality joints in preliminary tension tests were used in a further investigation to determine the effect of the amount of adhesive spread on the tensile strength of bonded specimens. All four bonding processes were found capable of producing good joints between aluminum and paper honeycomb when moderately heavy spreads were applied to both cores and facings. The use of lighter spreads or the application of adhesive to only the core or the facing usually resulted in lower-quality bonds, but with some of the adhesives the strength of the joints was sufficiently high for the lighter spreads to be considered satisfactory.

The tensile strengths obtained when using optimum spread conditions in fabricating specimens for the tests to determine the effect of spread were generally lower than those obtained with specimens prepared for the preliminary tests under similar bonding conditions. The rate of heating of the joints, the panel size, the variability of the strength of the core material, and the differences in the construction of the test specimens might account for the difference in joint strength results obtained in the two parts of this investigation.

Forest Products Laboratory
Madison, Wis., January 13, 1949

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2. Norris, C. B., and Mackin, G. E.: An Investigation of Mechanical Properties of Honeycomb Structures Made of Resin-Impregnated Paper. NACA TN 1529, 1948.

TABLE 1.- ADHESIVES AND BONDING PROCEDURES USED IN PREPARING TENSION SPECIMENS[a] FOR EVALUATION OF ADHESIVES

Adhesive and bonding process	Type of adhesive	Adhesive spread		Open-assembly period (hr) (b)	Precuring condition	Curing conditions (c)	Pressure (psi)
		On facings	On cores				
A	High-temperature-setting adhesive consisting of a liquid phenol resin and a polyvinyl-resin powder	Two medium-heavy brush coats of liquid; one application of powder	Dipped 1/16 inch in resin adhesive solution	21	None	25 minutes in press at 310° F	15
B	Metal-priming adhesive, same as A; secondary adhesive, an acid-catalyzed intermediate-temperature-setting phenol resin	Primer: Two medium-heavy brush coats of liquid; one application of powder Secondary: One medium-heavy brush coat on primer	Dipped 1/16 inch in secondary resin adhesive solution	(Primer) 21 (Secondary) 3	None	Primer: 30 minutes in press at 310° F Secondary: 1 hour in press at 220° F	(Primer) (d) (Secondary) 15
C	High-temperature-setting adhesive composed of thermosetting resins and synthetic rubbers	Six spray coats	Dipped 1/8 inch in resin adhesive solution	19	None	25 minutes in press at 325° F	15
D	Metal-priming adhesive, same as C; secondary adhesive, same as secondary adhesive in B	Primer: Six spray coats Secondary: One medium-heavy brush coat on primer	Dipped 1/16 inch in secondary resin adhesive solution	(Primer) 17 (Secondary) $3\frac{1}{2}$	None	Primer: 25 minutes in oven at 325° F Secondary: 1 hour in press at 220° F	(Primer) 0 (Secondary) 15
E	Metal-priming adhesive, same as C; secondary adhesive, a high-temperature-setting polyester resin	Primer: Six spray coats Secondary: One medium-heavy brush coat on primer	Dipped 1/16 inch in secondary resin adhesive solution	(Primer) 17 (Secondary) 22	None	Primer: 25 minutes in oven at 325° F Secondary: 40 minutes in press at 250° F	(Primer) 0 (Secondary) 15
F	Metal-priming adhesive, same as C; secondary adhesive, a high-temperature-setting phenol resin	Primer: Six spray coats Secondary: One medium-heavy brush coat on primer	Dipped 1/16 inch in secondary resin adhesive solution	(Primer) 17 (Secondary) 20	None	Primer: 25 minutes in oven at 325° F Secondary: 20 minutes in press at 320° F	(Primer) 0 (Secondary) 15
G	High-temperature-setting film adhesive similar in type to adhesive C	None	One sheet	--	----	25 minutes in press at 325° F	15
H	High-temperature-setting adhesive composed of two complementary parts: (1) A resin that has good adhesion to metal, and (2) a resin that has good flow properties to permit the use of moderate pressures	Four heavy brush coats	Coated twice by dipping 1/16 inch in the moderate-pressure resin adhesive solution	(High-temperature adhesive) $\frac{1}{2}$ (Low-temperature adhesive) $\frac{1}{2}$	None	30 minutes in press at 350° F	15
I	High-temperature-setting polyvinyl phenol resin	One medium-heavy brush coat	One medium-heavy brush coat	22	None	20 minutes in press at 310° F	15
J	Same as adhesive I, except of lower viscosity	One medium-heavy brush coat	One medium-heavy brush coat	25	None	20 minutes in press at 310° F	15
K	High-temperature-setting polyvinyl phenol resin	Two medium-heavy brush coats	Two medium-heavy brush coats	18	None	15 minutes in press at 300° F	15
L	High-temperature-setting polyvinyl phenol resin	One medium-heavy brush coat	Dipped 1/16 inch in resin adhesive solution	18	None	25 minutes in press at 320° F	15
M	High-temperature-setting polyvinyl phenol resin	Four medium-heavy brush coats	Four medium-heavy brush coats	20	22 minutes at 325° F following second coat and then an additional 10 minutes at 325° F following fourth coat (both in oven without pressure)	15 minutes in press at 325° F	15
N	High-temperature-setting polyvinyl phenol resin	Three medium-heavy brush coats	Dipped 1/16 inch in resin adhesive solution	18	15 minutes at 325° F without pressure in press	15 minutes in press at 310° F	15

[a]Tension specimens consisted of two 1-inch 17S-T4 aluminum-alloy cubes bonded directly to the opposite faces of a $\frac{1}{2}$-inch-thick section of resin-impregnated paper honeycomb the same as that described in reference 1.

[b]The adhesives were also air-dried between coats. When two or three coats of adhesive were applied, 1 hour of air-drying was used between coats; when four or six coats of adhesive were applied, 15 minutes of air-drying was used between coats.

[c]Curing conditions under pressure were those obtained at the joint. Assemblies were first pressed in the hot press for 1 to $2\frac{1}{2}$ hours to heat through the cubes and raise the temperature of the joint to the indicated curing temperature. Curing conditions for the adhesive specimens cured in ovens are given as the actual time that the aluminum cubes were in the oven.

[d]Contact pressure against copper caul.

TABLE 2.- RESULTS OF TENSION TESTS MADE AT 80° AND 200° F ON SANDWICH SPECIMENS[1] BONDED BY DIFFERENT BONDING PROCESSES

[Each value is the average of results of tests on eight specimens cut from one panel]

Bonding process (2)	Test results at 80° F						Test results at 200° F					
	Tensile strength (psi)	Type of failure (percent)					Tensile strength (psi)	Type of failure (percent)				
		Core	Adhesion to core	Adhesion to metal	Adhesion to primer	Cohesion of adhesive		Core	Adhesion to core	Adhesion to metal	Adhesion to primer	Cohesion of adhesive
A	503	100	0	0	0	0	358	100	0	0	---	0
B	323	46	4	0	50	0	250	33	0	0	67	0
C	219	3	0	0	0	97	184	0	0	0	---	100
D	435	71	0	0	28	1	356	54	2	0	35	9
E	192	0	0	0	100	0	234	0	0	0	100	0
F	241	1	4	0	95	0	162	0	0	0	100	0
G	95	0	0	0	0	100	95	0	0	0	---	100
H	252	6	0	93	1	0	146	0	0	100	---	0
I	399	99	0	1	0	0	275	59	0	32	---	9
J	420	89	4	7	0	0	281	48	0	20	---	32
K	491	90	3	7	0	0	362	99	0	0	---	1
L	436	100	0	0	0	0	292	83	10	7	---	0
M	502	94	6	0	0	0	292	88	7	0	---	5
N	402	99	0	0	0	1	231	77	0	23	---	0

[1]Sandwich specimens consisted of two 1-inch 17S-T4 aluminum-alloy cubes bonded directly to the opposite faces of a $\frac{1}{2}$-inch-thick section of resin-impregnated paper honeycomb the same as that described in reference 1.

[2]A general description of the adhesives used in each process is included in table 1.

TABLE 3.- RESULTS OF TESTS ON SANDWICH SPECIMENS[a] BONDED WITH VARIOUS AMOUNTS OF ADHESIVE A

[Each value is the average of results of tests on eight specimens cut from one panel unless otherwise noted]

Amount of dry adhesive spread per faying surface (g/sq ft) (b)		Tensile strength (psi)	Type of failure (percent)			
Facing	Core		Core	Adhesion to core	Adhesion to metal	Cohesion of adhesive
10-12 (liquid and powder)	None	[c]216	[c]0	[c]97	[c]0	[c]3
16-19 (liquid and powder)	None	[c]206	[c]4	[c]90	[c]0	[c]6
20-22 (liquid and powder)	None	187	0	47	1	52
23-25 (liquid and powder)	None	255	12	88	0	0
26-30 (liquid and powder)	None	[c,d]305	[c,d]50	[c,d]30	[c,d]0	[c,d]20
None	6-9 (liquid and powder)	[c]227	[c]32	[c]0	[c]4	[c]64
None	10-12 (liquid and powder)	[c]277	[c]14	[c]86	[c]0	[c]0
None	23-25 (liquid and powder)	[d]265	[d]32	[d]68	[d]0	[d]0
None	25-30 (liquid and powder)	[d]145	[d]15	[d]85	[d]0	[d]0
None	60-65 (liquid and powder)	[d]159	[d]21	[d]52	[d]27	[d]0
6-9 (liquid and powder)	10-15 (liquid only)	318	9	91	0	0
10-15 (liquid and powder)	10-15 (liquid only)	[c,d]245	[c,d]40	[c,d]60	[c,d]0	[c,d]0
15-20 (liquid and powder)	6-9 (liquid only)	[c]345	[c]78	[c]0	[c]0	[c]22
15-20 (liquid and powder)	10-15 (liquid only)	[c]261	[c]43	[c]57	[c]0	[c]0
15-20 (liquid and powder)	20-25 (liquid only)	305	4	0	0	96
15-20 (liquid and powder)	30-35 (liquid only)	[c,d]367	[c,d]29	[c,d]36	[c,d]1	[c,d]34
25-30 (liquid and powder)	10-15 (liquid only)	331	27	73	0	0

[a]Sandwich specimens consisted of two 1-inch 17S-T4 aluminum-alloy cubes bonded to sections of 0.020-inch 24S-T3 alclad aluminum alloy which were bonded to the opposite faces of $\frac{1}{2}$-inch-thick resin-impregnated paper honeycomb core the same as that described in reference 1. The joint between the metal face and the honeycomb core was under test.

[b]The spread of adhesive (a two-part adhesive consisting of a liquid phenol resin and a polyvinyl powder) was varied as shown. The other bonding conditions (open-assembly time, 21 hours; curing, 25 minutes at 310° F; and pressure, 15 psi) were held constant.

[c]Average of values obtained from tests on 16 specimens, 8 from the original panel and 8 from one additional panel made for checking original results.

[d]Test results obtained on panels in which some blistering occurred. Blistering was mainly in the part of the core which expanded out of the sides of the sandwich panel.

TABLE 4.- RESULTS OF TENSION TESTS ON SANDWICH SPECIMENS[a] BONDED BY THE TWO-STAGE BONDING PROCESS D AND USING VARIOUS AMOUNTS OF THE SECONDARY ADHESIVE

[Each value is the average of results of tests on eight specimens cut from one panel unless otherwise noted]

Amount of wet secondary-adhesive spread per faying surface (g/sq ft) (b)		Tensile strength (psi)	Type of failure (percent)				
Facing	Core		Core	Adhesion to core	Adhesion to primer	Cohesion of adhesives	Primer adhesion to metal
10-15	None	148	29	0	68	3	0
15-20	None	[c]270	[c]32	[c]19	[c]49	[c]0	[c]0
20-25	None	[c]332	[c]50	[c]0	[c]50	[c]0	[c]0
30-35	None	294	97	0	3	0	0
35-40	None	363	66	0	23	0	11
50-55	None	419	82	0	18	0	0
None	6-9	143	7	0	76	17	0
None	15-20	114	2	0	98	0	0
None	35-40	[c]220	[c]30	[c]0	[c]68	[c]2	[c]0
None	110-115	227	38	0	62	0	0
6-10	4-6	221	11	10	79	0	0
6-10	6-10	[c]266	[c]33	[c]0	[c]67	[c]0	[c]0
6-10	10-15	286	43	0	57	0	0
6-10	15-20	291	27	0	72	0	1
6-10	20-25	330	21	0	79	0	0
10-15	6-10	[c]222	[c]21	[c]1	[c]78	[c]0	[c]0
10-15	15-20	269	1	0	99	0	0
10-15	20-25	282	14	0	86	0	0
10-15	25-30	320	93	0	6	1	0
20-25	6-10	273	38	0	62	0	0

[a]Sandwich specimens consisted of two 1-inch 17S-T4 aluminum-alloy cubes bonded to sections of 0.020-inch 24S-T3 alclad aluminum alloy which were bonded to opposite faces of a $\frac{1}{2}$-inch-thick resin-impregnated paper honeycomb core the same as that described in reference 1. The joint between the metal face and honeycomb core was under test.

[b]The spread of the secondary adhesive, an acid-catalyzed, intermediate-temperature-setting phenol resin, was varied as indicated. Only the facings were primed with a 0.004-inch film of the priming adhesive, and were cured for 25 minutes at 325° F prior to the secondary bonding. The other bonding conditions with the secondary adhesive (open-assembly time, $3\frac{1}{2}$ hours; curing 1 hour at 220° F; and pressure, 15 psi) were held constant.

[c]Average of values obtained from tests on 16 specimens, 8 from the original panel and 8 from one additional panel made for checking original results.

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TABLE 5.- RESULTS OF TENSION TESTS ON SANDWICH SPECIMENS[a]

BONDED WITH VARIOUS AMOUNTS OF ADHESIVE K

[Each value is the average of results of tests on eight specimens cut from one panel unless otherwise noted]

Amount of dry adhesive spread per faying surface (g/sq ft) (b)		Tensile strength (psi)	Type of failure (percent)			
Facing	Core		Core	Adhesion to core	Adhesion to metal	Cohesion of adhesive
10-12	None	12	2	98	0	0
15-20	None	38	2	96	0	0
20-25	None	29	0	93	0	7
None	7-9	[c]37	[c]4	[c]96	[c]0	[c]0
None	25-30	163	8	92	0	0
8-10	7-9	100	11	74	15	0
8-10	30-35	183	36	19	0	45
10-15	10-15	246	18	82	0	0
15-20	10-15	271	8	92	0	0
15-20	20-25	379	86	14	0	0

[a]Sandwich specimens consisted of two 1-inch 17S-T4 aluminum-alloy cubes bonded to sections of 0.020-inch alclad aluminum alloy which were bonded to the opposite faces of a $\frac{1}{2}$-inch-thick resin-impregnated paper honeycomb the same as that described in reference 1. The joint between the metal face and honeycomb was under test.

[b]The spread of the adhesive, a polyvinyl phenol resin, was varied as indicated. The other bonding conditions (open-assembly time, 18 hours; precuring, 9 minutes at 300° F in hot press without pressure applied; curing, 15 minutes at 300° F; and pressure, 15 psi) were held constant.

[c]Average of values obtained from tests on 16 specimens, 8 from the original specimen and 8 from one additional panel made for checking original results.

TABLE 6.- RESULTS OF TENSION TESTS ON SANDWICH SPECIMENS[a] BONDED

WITH VARIOUS AMOUNTS OF ADHESIVE L

[Each value is the average of results of tests on eight specimens cut from one panel unless otherwise noted]

Amount of dry adhesive spread per faying surface (g/sq ft) (b)		Tensile strength (psi)	Type of failure (percent)			
Facing	Core		Core	Adhesion to core	Adhesion to metal	Cohesion of adhesive
10-15	None	192	0	100	0	0
15-20	None	218	0	100	0	0
20-25	None	[c]226	[c]4	[c]96	[c]0	[c]0
30-35	None	172	1	99	0	0
None	5-7	227	19	0	0	81
None	[d]10-15	147	0	95	5	0
None	[d]15-20	247	3	95	2	0
None	15-20	[c]258	[e]51	[e]21	[e]0	[e]28
None	20-25	[c, e]251	[c, e]42	[c, e]48	[c, e]0	[c, e]10
None	80-85	200	0	0	0	100
[d]8-10	[d]3-5	116	3	97	0	0
8-10	5-7	138	3	97	0	0
[d]8-10	[d]10-15	227	25	75	0	0
8-10	15-20	256	99	0	0	1
8-10	25-30	333	79	8	0	13
10-15	8-10	293	62	11	6	21
10-15	15-20	[e]246	[e]94	[e]3	[e]0	[e]3
10-15	20-25	[e]314	[e]99	[e]0	[e]0	[e]1
10-15	55-60	334	97	0	3	0

[a]Sandwich specimens consisted of two 1-inch 17S-T4 aluminum-alloy cubes bonded to sections of 0.020-inch alclad aluminum alloy which were bonded to the opposite faces of a $\frac{1}{2}$-inch-thick resin-impregnated paper honeycomb the same as that described in reference 1. The joint between the metal face and honeycomb core was under test.

[b]The spread of adhesive (a polyvinyl phenol resin) was varied as indicated. The other bonding conditions (open-assembly time, 18 hours; curing, 25 minutes at 320° F; and pressure, 15 psi) were held constant.

[c]Average of values obtained from tests on 16 specimens, 8 from the original panel and 8 from one additional panel made for checking original results.

[d]Panels in which the adhesive was precured for 20 minutes at 200° to 220° F after 18 hours of open assembly.

[e]Test results obtained on panels in which some blistering occurred. Blistering was mainly in the part of the core which expanded out of the sides of the sandwich panel.

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Figure 1.- Cutting of fabricated blocks of paper honeycomb material into sections with a circular saw.

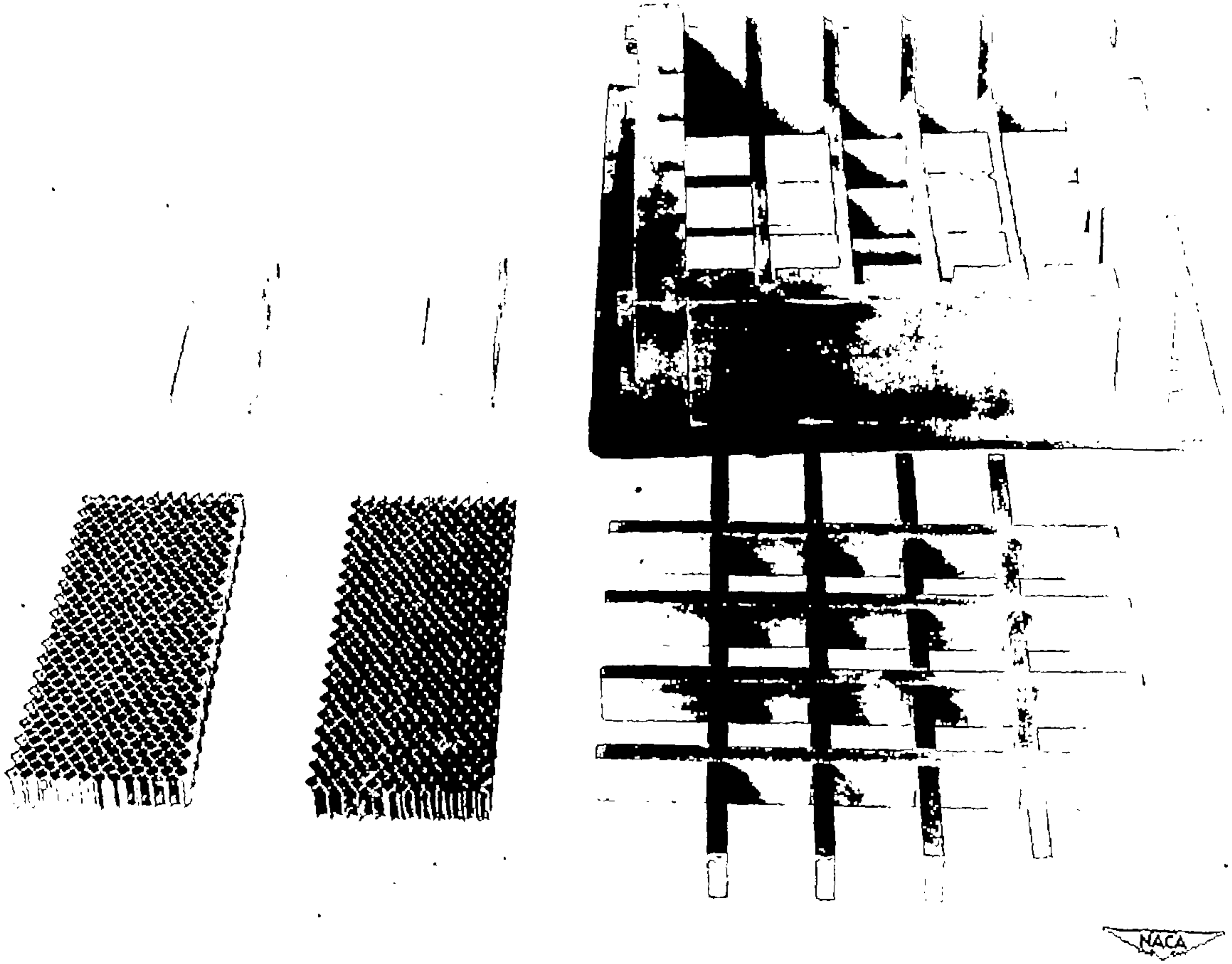

Figure 2.- Sections of paper honeycomb core material, aluminum cubes, and alining jig used in fabrication of sandwich specimens for tension tests.

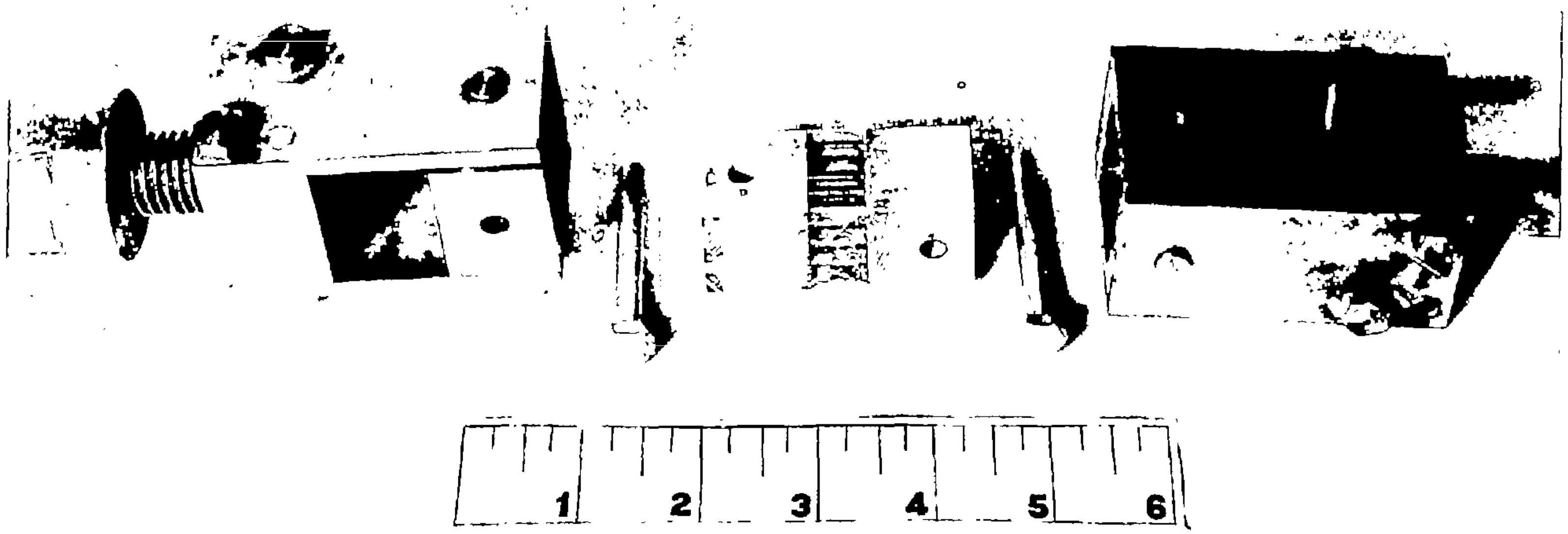

Figure 3.- Specimen and fittings used for tensile tests of sandwich specimens of aluminum bonded to paper honeycomb core.

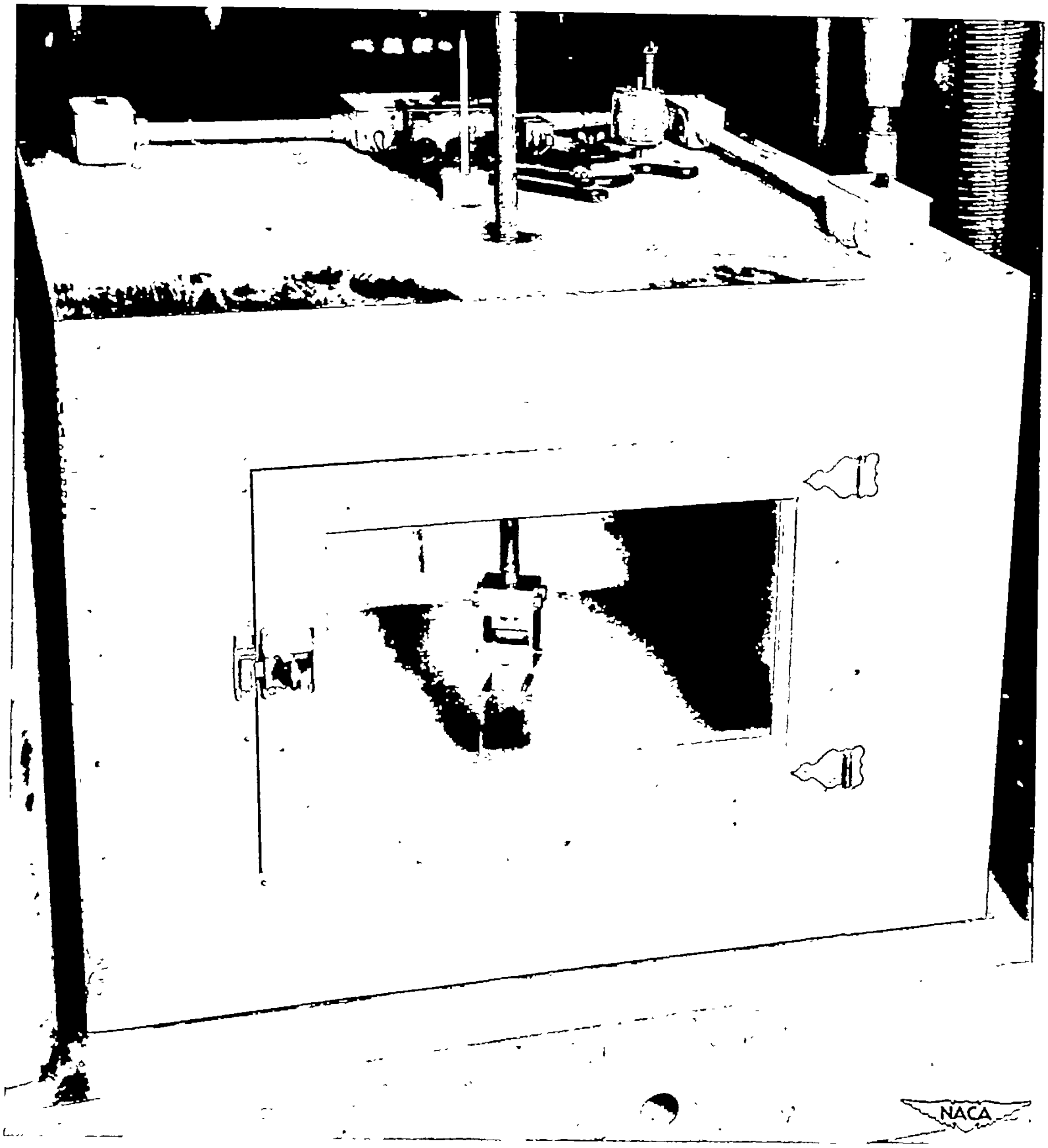

Figure 4.- Insulated heated cabinet in which sandwich specimens were tested in tension at 200° F.

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